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Use of Remote Sensing to Map the Areal Distribution of 'Cladophora glomerata' at a Site in Lake Huron

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The areal distribution of the benthic alga Cladophora glomerata and the percent areal coverage of Cladophora within 45.8 m (150 ft) by 15.3 m (50 ft) model cells for a 2.8 km length of Lake Huron shoreline at Harbor Beach, Michigan, are determined by remote sensing techniques. Data were acquired on 21 July 1979, a calm, clear day over Lake Huron at an altitude of 305 m with an eleven-channel modular multispectral scanner mounted in a NASA C-131 aircraft. Cladophora is determined by a conventional maximum likelihood statistical supervised classification technique employing three of the scanner bands. An intensive field survey of the study site indicated that the computer classified imagery is representative of the Cladophora distribution at Harbor Beach. Classification accuracy is not determined because the site was not mapped by ground surveys. The percent of areal coverage of model cells by Cladophora ranges from 0% to 93%. Calculations based on these percentages indicate that the alga occupies an area of 38,704 m^2 at the study site. Overlapping flight lines resulted in duplicate measurements of many model cells. The reproducibility of results for these areas is good (R = 0.86 and standard error of estimate of 9.9%) when suitable well-defined Cladophora training sites are common to adjacent data sets. The reproducibility decreases in the absence of this condition.

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THE USE OF REMOTE SENSING TO MAP THE AREAL DISTRIBUTION OF *CLADOPHORA GLOMERATA* AT A SITE IN LAKE HURON

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ABSTRACT. *The areal distribution of the benthic alga* Cladophora glomerata *and the percent areal coverage of* Cladophora *within 45.8 m (150 ft) by 15.3 m (50 ft) model cells for a 2.8 km length of Lake Huron shoreline at Harbor Beach, Michigan, are determined by remote sensing techniques. Data were acquired on 21 July 1979, a calm, clear day over Lake Huron at an altitude of 305 m with an eleven-channel modular multispectral scanner mounted in a NASA C-131 aircraft.* Cladophora *is determined by a conventional maximum likelihood statistical supervised classification technique employing three of the scanner bands. An intensive field survey of the study site indicated that the computer classified imagery is representative of the* Cladophora *distribution at Harbor Beach. Classification accuracy is not determined because the site was not mapped by ground surveys. The percent of areal coverage of model cells by* Cladophora *ranges from 0% to 93%. Calculations based on these percentages indicate that the alga occupies an area of 38,704 m² at the study site. Overlapping flight lines resulted in duplicate measurements of many model cells. The reproducibility of results for these areas is good (R* = 0.86 and standard error of estimate of 9.9%) when suitable well-defined Cladophora *training sites are common to adjacent data sets. The reproducibility decreases in the absence of this condition.*

INTRODUCTION

Local nuisance growth of the benthic, filamentous green alga *Cladophora glomerata* in Lake Huron is associated with point sources of nutrients (Auer and Canale 1981, and Neil and Owen 1964). Present research studies directed at the development of a mathematical model capable of predicting the utility of various nutrient control strategies on problem *Cladophora* growth in the Great Lakes are being conducted by The University of Michigan under the sponsorship of the USEPA Large Lakes Research Station at Grosse Ile, Michigan. The basis of this effort is an intensive field and laboratory program designed to gain a more complete understanding of the ecology of the alga. Key elements of this program are a knowledge of the spatial distribution and seasonal growth characteristics of the organism.

In 1979, NASA Lewis Research Center was requested to conduct a remote sensing experiment to determine the feasibility of measuring the areal distribution of the alga for a 2.8 km length of Lake Huron shoreline from Duck Blind Point to Rock Falls Creek at Harbor Beach, Michigan, (Figure 1)

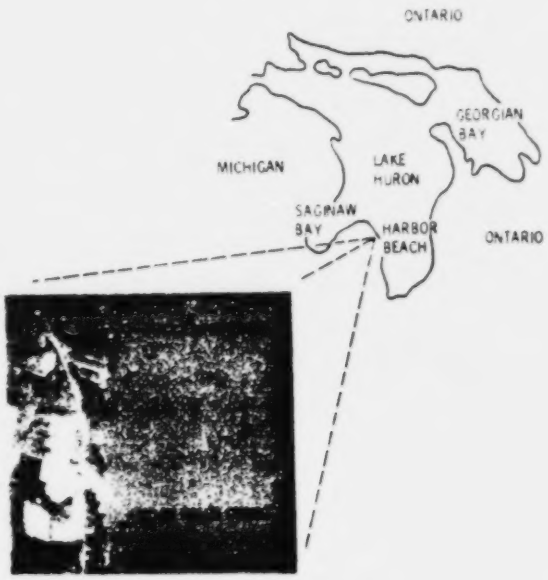


FIG. 1. Study site location. Inset—Channel 2 (440–490 nm) scanner imagery of Harbor Beach, Michigan.

using aircraft multispectral scanner data. Further, this distribution was to be measured as the percent coverage by *Cladophora* within 45.8 m (150 ft) by 15.3 m (50 ft) model cells along the shore. Extensive algal growth in this region is promoted by the Harbor Beach Wastewater Treatment Plant which discharges a soluble reactive phosphorus loading of 1.35 kgP/day at the mouth of Spring Creek. These data would serve as input to the University of Michigan model. Canale and Auer (1982) provide a description of the model format and the physical and chemical environment of the site.

Remote sensing techniques have been successfully employed to measure *Cladophora* and other bottom features (Lyzenga 1979, Lyzenga *et al.* 1979, and Wezernak *et al.* 1974). These techniques made use of multispectral scanner band ratios, radiative transfer models, and conventional classification routines. The techniques were designed to recognize various bottom types while accounting for the variance in bottom spectral signature due to the attenuation by the intervening water column for variable depths down to several meters.

The feasibility study presented here recognizes the effect of volume scattering on bottom-reflected radiance. However, in this region, *Cladophora* growth is basically limited to a water depth of less than 1.0 m and predominantly flouishes in 0.3 to 0.6 m of water. Thus, for the purpose of this study, the effect of the water column is considered negligible and the areal extent of *Cladophora* is examined by conventional classification techniques.

DATA ACQUISITION

Remote Sensing Data

The remote sensing data for this experiment were obtained on 21 July 1979 with an eleven channel (see Table 1) modular multispectral scanner (Bendix 1975) mounted in a NASA C-131 aircraft. The first eight bands of the scanner are in the visible spectrum between 410 and 720 nm with bandwidths of approximately 40 nm, while bands nine and ten are centered in the near infrared at 815 and 1,015 nm with bandwidths of 90 nm. The eleventh band is in the thermal IR at 11,000 nm. Research conditions for the acquisition of aircraft data were excellent as the sky was clear and the lake calm. Data were obtained at an aircraft altitude of 305 m yielding a nadir pixel with a spatial resolution of approximately .76 m in the flight line direction. Six overlapping flight lines (Figure 2)

TABLE 1. Specifications of the modular multiband scanner (M²S)

Channel number	Center wavelength, nm	Bandwidth, nm
1	410	60
2	465	50
3	515	50
4	560	40
5	600	40
6	640	40
7	680	40
8	720	40
9	815	90 (Near IR)
10	1 015	90 (Near IR)
11	11 000	2500 (Thermal)

M²S mounted in NASA C-131 aircraft

Altitude, m	305
Ground resolution in the flight direction, m	0.76
Swath width, m	915

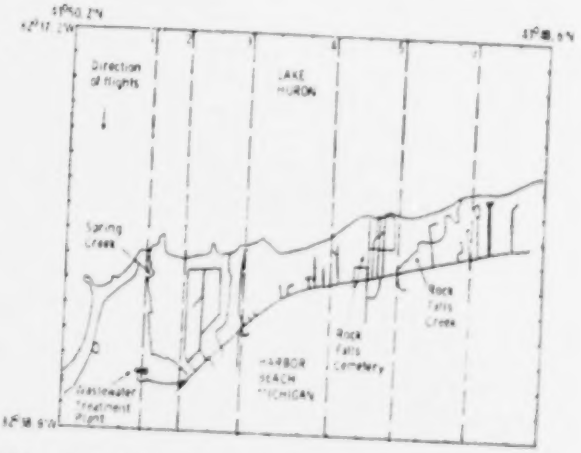


FIG. 2. Subaircraft tracks (1–6) flown over Harbor Beach, Michigan, on 7/21/79 — — — Subaircraft tracks.

were flown in the solar plane with the sun aft (offshore to onshore) for zenith angles between 50° and 60° to minimize sun glint. Color 70-mm aerial photographs were taken for documentation and qualitative observations.

"Surface" Data

The research flights were made to coincide with a period of intensive field surveys being conducted by The University of Michigan. The various parameters measured included *Cladophora* biomass, *Cladophora* bed locations, presence of other algal

species, and available algal substrate. A complete set of these measurements was concluded on 17 July 1979. These key data were essential for the selection of training sites during the multispectral data classification procedures.

DATA PROCESSING

Prior to classification, two pre-processing steps were performed on the digital data of each flight line: (1) radiometric correction for scan angle variations and (2) geographic coordinate registration for mapping purposes. The first step is required to normalize the radiance values at nonzero scan angles to nadir radiance values to correct for the atmospheric contributions which cause variations in upwelling intensity with scan angle. The correction procedure is made empirically using an algorithm based on an atmospheric scattering model.

Geographic coordinate registration is required in order to assign grid coordinates (latitude and longitude) to each element of data (pixel and scanline numbers). Conversely, registration enables the extraction of the digital data corresponding to specific grid coordinates. This process includes corrections for aircraft drift and roll, scanner look-angle rectification, and scaling along the flight lines.

A conventional maximum-likelihood statistical supervised computer classification technique (Swain 1973) was used to categorize the multispectral data. This computer analysis is based on the "calibration" of the computer with training sites of predetermined classes. These classes exhibit different spectral signatures which can be used to statistically assign each pixel to a specific class. For this study three classes were used: (1) land areas to accurately delineate the shoreline; (2) water areas (including all features in the water and on the bottom such as exposed rocks and sand, with the exception of *Cladophora*); and (3) *Cladophora* areas. The accuracy and quantitative results obtained from this technique are highly dependent on training site selection. The proper selection of training sites was made possible by cooperation with University of Michigan personnel in identifying specific bottom features.

The final step after the classification was to determine the area occupied by *Cladophora* for each of the 45.8 m by 15.3 m model cells. This data output format was dictated by the input requirements of the University of Michigan model. A computer program was designed to define the latitude and longitude points in the grid system, including the boundaries of each individual model cell which consist of an array of approximately 720 pixels. As all classified pixels were map-registered, they could be assigned to respective model cells. The percent of the area covered by *Cladophora* for each cell was determined by the percent of *Cladophora* classified pixels in the array. For areas overlapped by two flight lines, the mean of the values for duplicate cells was used.

RESULTS AND DISCUSSION

The Spring Creek region exhibited the most intense *Cladophora* growth within the Harbor Beach study area (Figure 3). The results presented here will focus on this region. Single band imagery of channels 2, 3, and 8 for flight line 2 are displayed in Figure 4. The basic *Cladophora* distribution is evident in the shorter, water-penetrating bands 2 and 3. The exact delineation of *Cladophora* from other water features and bottom types using single band imagery is qualitative and strongly influenced by the color bar levels that were selected. However, the identification and location of training sites can be determined from this imagery. The longer wavelength of band 8 does not penetrate the water surface and serves primarily to delineate the land areas and shoreline.

The three-category classification (water, land, and *Cladophora*) was performed using only bands 2, 3, and 8. Training sites were selected for several water types including deeper open water, nearshore water, sandy and muddy bottom, overall land features, and areas of very high *Cladophora* density. Figure 5 shows the characteristic separation between classes for the three bands that were considered.

The resulting color coded computer classified image (Figure 6) is a good representation of the area as indicated by comparison with the color aerial photograph (Figure 3). The red color indicates unclassified pixels which are primarily roads, houses, and the beach. These areas are unclassified as a result of selecting land training sites which consist of large arrays (up to 100 × 100 pixels) in which the spectral signatures of these smaller features are masked by the dominance of foliage.

A final classified image of the study area is shown by the mosaic of the flight lines presented in Figure 7. In addition to an intense algal growth comprising a 0.3-km stretch of shore near Spring

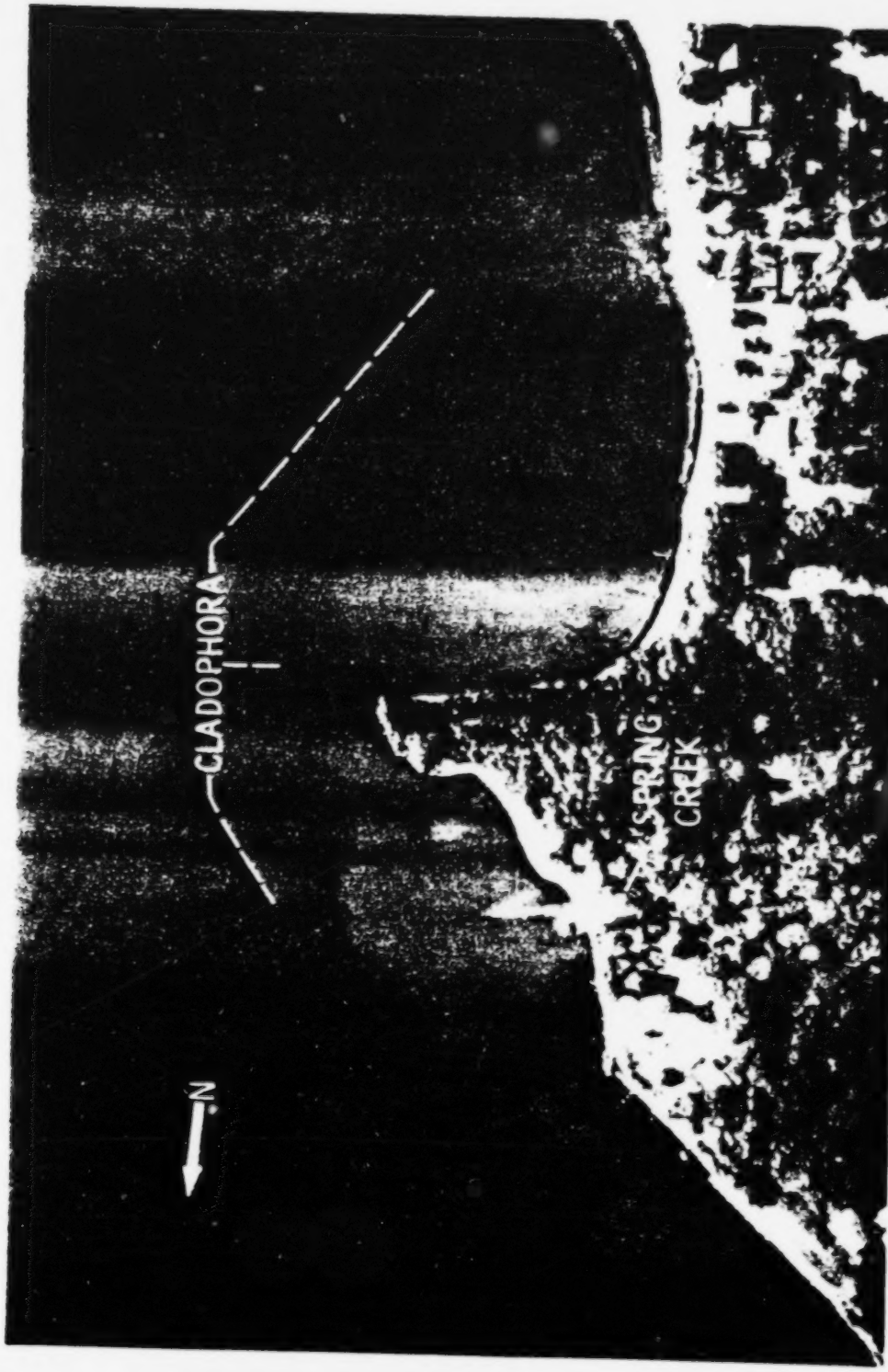
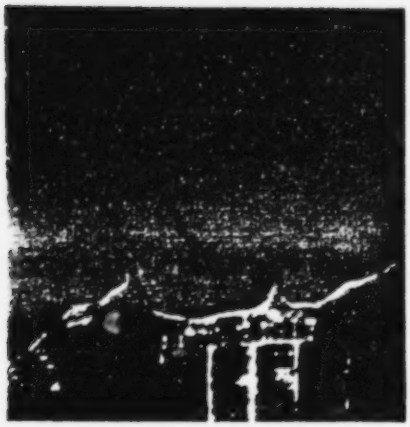
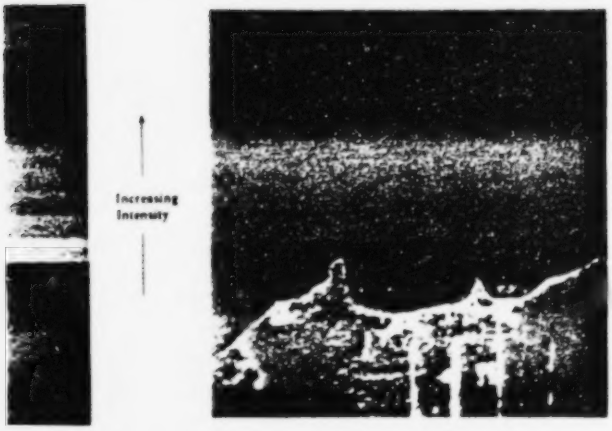


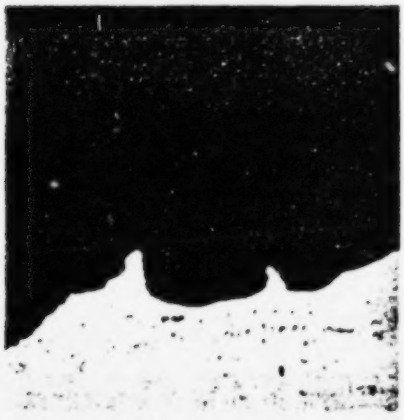
FIG. 3. Color, aerial photograph (mosaic) of intense Cladophora *growth in the Spring Creek region of Harbor Beach, Michigan (altitude - 305 m).*



(a) Channel 2, 440 to 490 nm.



(b) Channel 3, 490 to 540 nm.



(c) Channel 8, 700 to 740 nm.

FIG. 4. Single band scanner imagery of the channels selected for supervised classification (Flight line 2).

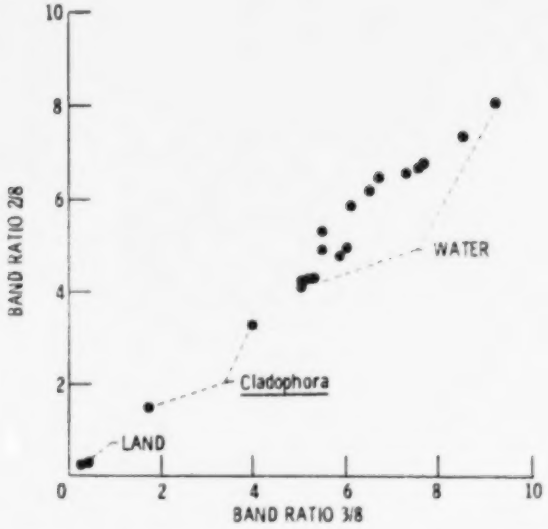


FIG. 5. Band ratio cluster representation of training site data.

Creek, there are patches of *Cladophora* beds at Duck Blind Point, on submerged jetties just north of Rock Falls Cemetery, and at the mouth of Rock Falls Creek. Using this image and the results of the University of Michigan survey of the *Cladophora* beds, it was concluded that the classified imagery is representative of the *Cladophora* distribution at Harbor Beach. There is no quantitative statistical comparison between aircraft data and ground data.

The last step of the feasibility study is the determination of the percent *Cladophora* for model cells along the shore. An example of the grid system is shown in Figure 8. The numbers in the grid represent the percent of the 45.8 m by 15.3 m cells occupied by *Cladophora*. The values range from 0% to as high as 93%. Through the use of these percentages, the area covered by *Cladophora* in Figure 8 is calculated to be approximately 23,640 m^2. Further, this procedure can be employed for the entire shoreline. The resulting areal coverage of *Cladophora* for the Harbor Beach study site is 38,704 m^2.

Since flight lines overlapped, there are duplicate measurements for many grid cells. As stated earlier, classified pixels for these areas represent the average values for two flight lines. The reproducibility of these overlap areas was examined. An example of these data is shown in Figure 9. The curves represent the *Cladophora* percentages taken from column 17 and 20 of Figure 8 for flight lines 2 and 3. While the data of Figure 9A are very similar

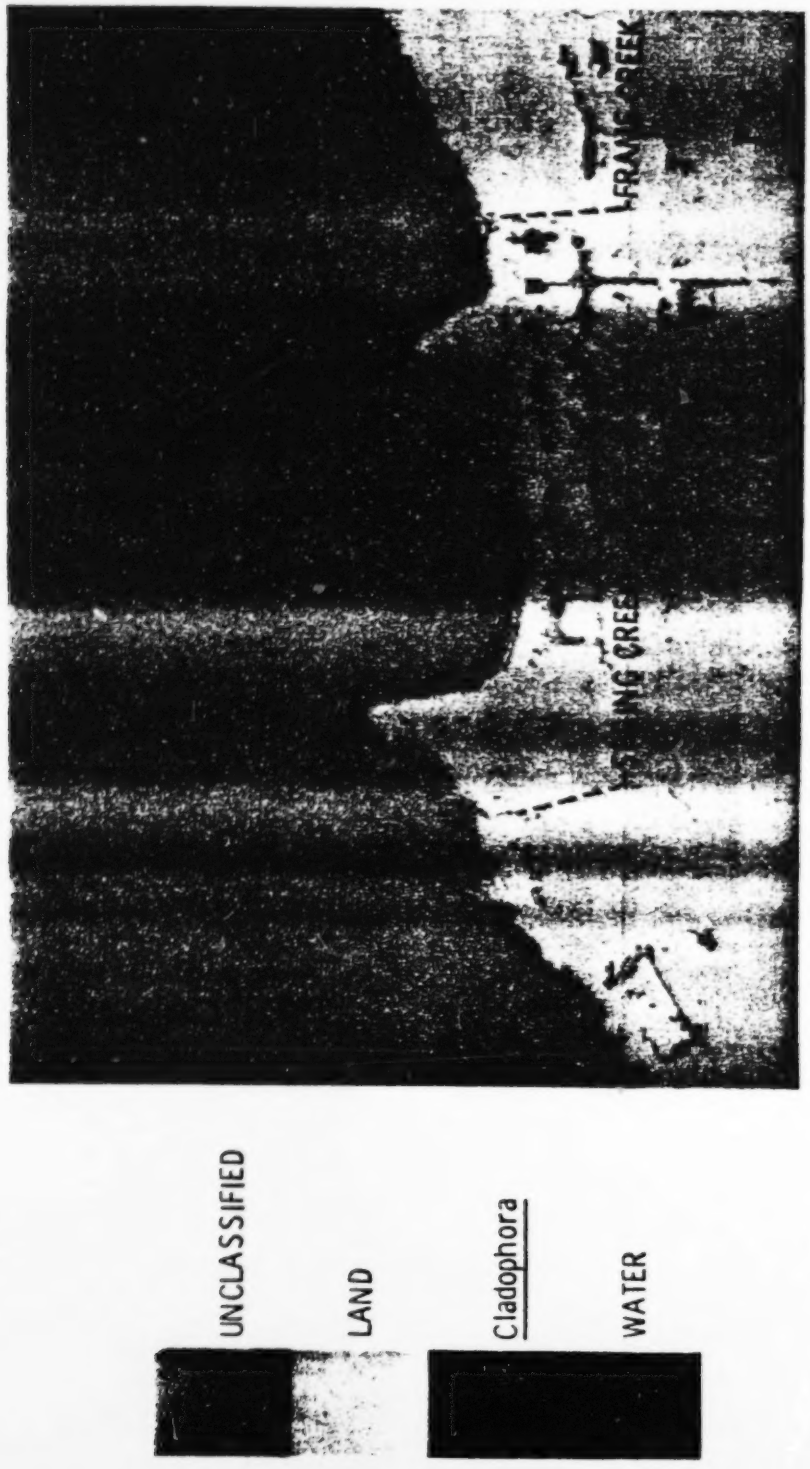


FIG. 6. Color-coded, computer-classified imagery of the Spring Creek region of Harbor Beach, Michigan (Flight line 2).

FIG. 7. Color coded, computer-classified imagery of the Harbor Beach study site.

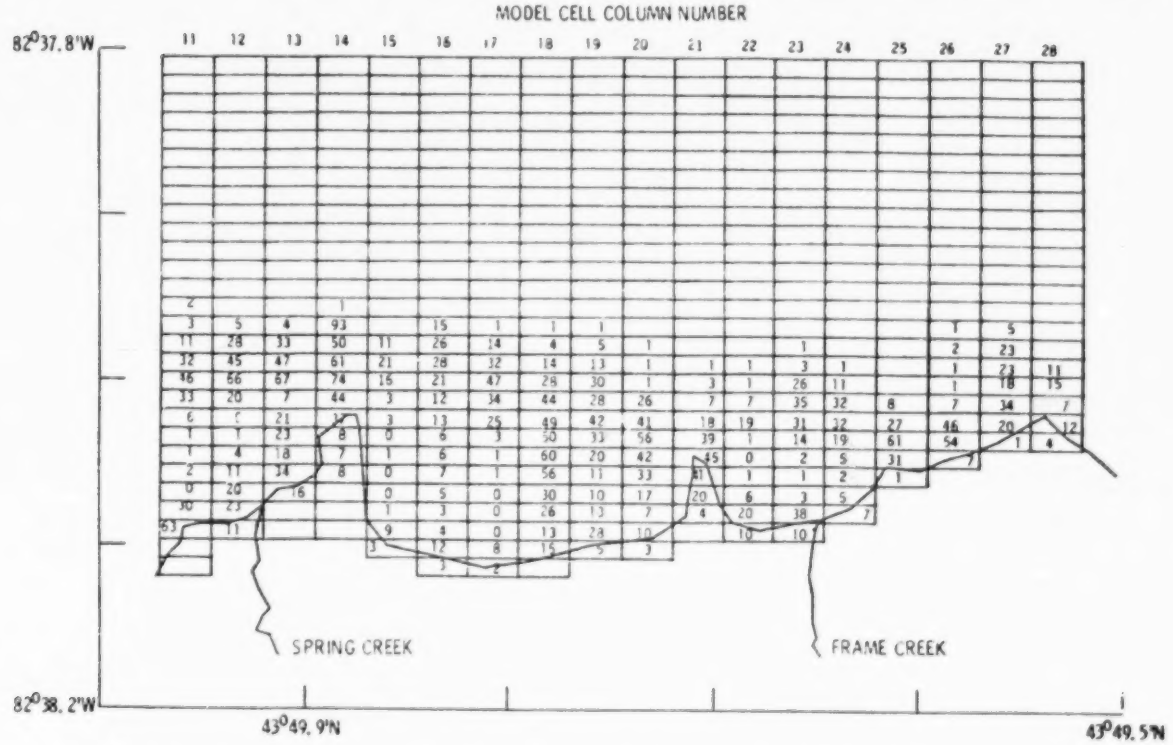


FIG. 8. Model cell grid with calculated percentages of Cladophora *for each cell. Total area coverage of* Cladophora *for this region is 23,640 m². The mean value for overlap cells are presented.*

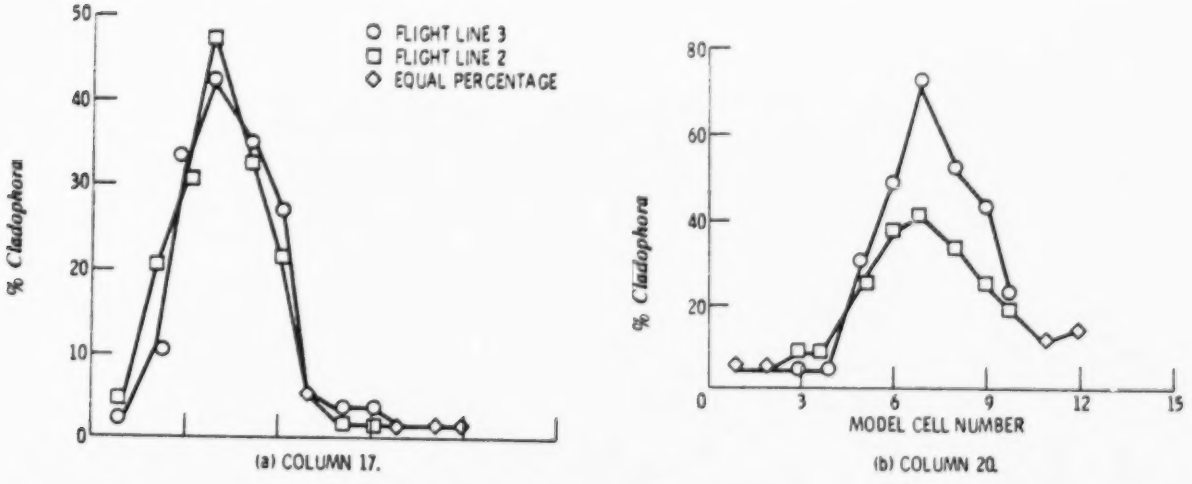


FIG. 9. Comparison of calculated percent Cladophora *for model cells overlapped by two flight lines (columns 17 and 20 selected from Fig. 8).*

in distribution and magnitude, the data of Figure 9B are similar in distribution but with different percentages.

A scatter plot of the percentages measured on flight 3 plotted versus those measured on flight 2 is shown in Figure 10. For the 144 data points, a least square fit yielded the equation $Y = 1.23 + 1.124X$ where Y = flight 3 data and X = flight 2 data. The correlation coefficient is .86 and the standard error of estimate is 9.9%. For this particular data set, there were two *Cladophora* training sites of high concentration that were common to both flight lines and had well-defined locations. This is a key factor for accurate classification. Other error can be introduced by the geographic coordinate map registration technique where pixel mislocations can occur.

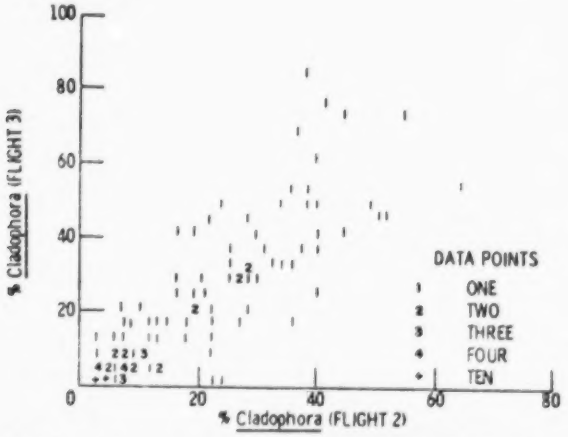


FIG. 10. Scatter plot of calculated percent* Cladophora *for model cells in the overlap region of flight 2 and flight 3 (N = 144, R = 0.86, the standard error of estimate = 9.9% and Y (flight 3) = 1.23 + 1.124 × (flight 2).

For flight lines further south, where the *Cladophora* concentration decreases, it was difficult to obtain large area, homogeneous training sites common to both data sets. This situation in combination with possible geometric registration errors yielded less accurate comparisons in overlap areas.

CONCLUSIONS

A conventional maximum likelihood statistical supervised classification technique employing three multispectral scanner bands was used to define the areal extent of *Cladophora* for a 2.8 km study site at Harbor Beach, Michigan. This procedure was employed to calculate percentages of 45.8 m by 15.3 m model cells that were occupied by *Cladophora*. Total areal coverage by the benthic alga at the study site is calculated to be 38,704 m^2. These data provided input to a University of Michigan mathematical model developed to predict the utility of various nutrient control strategies on problem *Cladophora* growth in the Great Lakes.

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